Variation in age-at-1st reproduction & age-related survival of Adélie penguin in relation to colony size, breeding status, & environmental variation.

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Introduction:

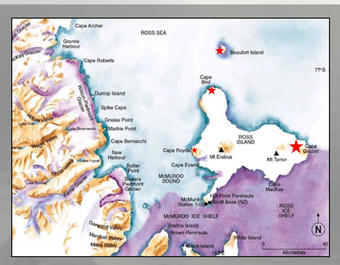
Similar to other seabirds, the Adélie penguin (*Pygoscelis adeliae*) exhibits high survival, delayed maturation & high breeding philopatry, although we previously confirmed that survival & breeding philopatry can vary in response to environmental variation (Dugger et al. 2010). Our long-term efforts to collect data on marked, known-age individuals in a 3-colony meta-population on Ross Island, now allow us to investigate complex questions regarding age-related survival, & age-at-1st reproduction in relation to colony size, & environmental variation. Understanding these population dynamic components of this system may help us understand the mechanism responsible for maintaining the large degree of size discrepancy (orders of magnitude differences) amongst these 3 colonies & the role annual environmental variation plays in maintaining this system.,

Objective:

1. Estimate age-related survival & understand how it varies in relation to colony size, reproductive status & environmental variation.
2. Estimate age-at-1st reproduction & determine whether it varies in relation to colony size.

Study Area:

Ross Island, Antarctica, 1996-2008
1. Cape Royds (~1500 pairs)
2. Cape Bird (~45,000 pairs)
3. Cape Crozier (~250,000 pairs)



Methods:

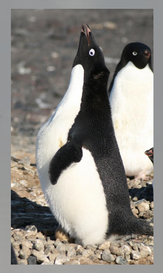
1. Penguin chicks were banded just prior to fledging w/stainless steel flipper tags - 25,920 total.
   - 3,968 Cape Royds
   - 9,879 Cape Bird
   - 12,073 Cape Crozier
2. Colonies were searched & bands were read every 2-to 7-days during entire breeding season (Nov – Jan).
3. Reproductive status & nests of breeding birds monitored until chicks crèched.

Program MARK

Analysis:

1. A multistate mark-recapture model with unobservable states was used to estimate apparent survival (Φ), resighting rates (p), & transition probabilities (ψ: movement rates between reproductive states & colonies).
2. Program MARK was used to generate estimates & model selection results.
3. An information theoretic approach was used to evaluate *a priori* models & strength of effects.

Covariates:
- Reproductive status (rs): PR=Pre-breeder, BR=Breeder, NB=Non-breeder
- Colony (c): Cp Royds (R), Cp Bird (B), Cp Crozier (C)
- General time effects (t), Iceberg presence (Ice), Ice cover (IC), polynya presence (P), Distance to ice edge during the breeding season (DIST)



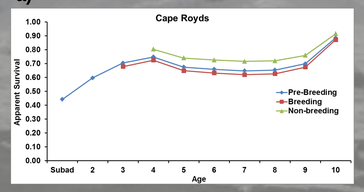
Results:

Table 1: Model selection results for top four Φ & Ψ models, all with best model structure for resighting rates [p(c*PR,BR=NB+a+t)].

Model	Δ AIC_c	AIC_c wt	*k*
Φ(R,B=C+rs+a+t), Ψ(PUPR,PUBR, PRBR*age, BR,NB)	0.00	0.62	107
Φ(R,B=C,rs*a+t), Ψ(PUPR,PUBR,PRBR*age, BR,NB)	1.48	0.48	129
Φ(R,B=C+rs+a+t), Ψ(PUPR,PUBR,PRBR*age, BR,NB+c)	4.02	0.08	109
Φ(R,B=C+rs+a+DIST), Ψ(PUPR,PUBR,PRBR*age, BR,NB+c)	40.49	0.00	97

Survival
- Lowest at Cp Royds; Cp Bird=Cp Crozier (Fig 1)
- Non-breeders > Pre-breeders > Breeders (Fig 1)
- Age-related differences, with Φ increasing through age 4, declining through mid-ages & then increasing again at the oldest age class (Fig 1).
- Competitive model (Table 1) suggests some support for an interaction between reproductive status & age.
- High annual variation, largely unexplained by environmental covariates (ex: Fig 2), although there is some support for a negative effect of distance to the ice edge during the breeding season (4th model; Table 1; β=-0.0.10, 95%CI -0.011 to -0.009).

a)



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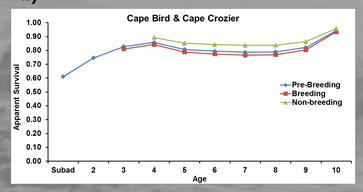

Fig1: Mean apparent survival across all years at Cp Royds (a) & Cps Bird & Crozier (b) by reproductive status & age class.

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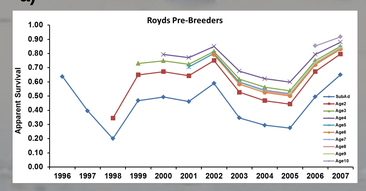
a)



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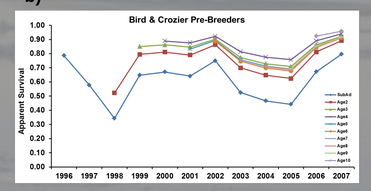
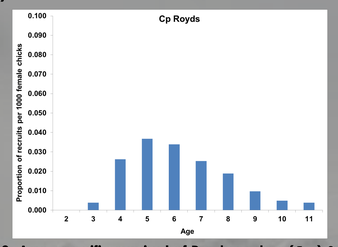


Fig 2: Apparent survival by age class & year for Pre-breeding birds at Cp Royds (a) & Cps Bird & Crozier (b).

Recruitment & Breeding Propensity
- Strong age-related variation in the probability of recruitment (Ψ_{PBtoBR})
- No penguins bred <3 years of age (Figure 3).
- No measurable difference in age-related recruitment rates between colonies.
- Breeders don't breed every year (Ψ_{BRtoNB} = 0.22 to 0.42 depending on age)

a)



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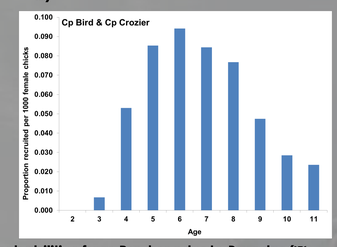

Fig 3: Age-specific survival of Pre-breeders (Φ_{PB}) & transition probabilities from Pre-breeder to Breeder (Ψ_{PBtoBR}) averaged over years & applied to a hypothetical group of 1000 female Adélie penguin chicks (starting at age 0) for Cp Royds (a) and Cps Bird & Crozier (b).

Cp Royds:
- 16% of every 1000 female chicks produced recruit by age 11
- Mean age at 1st reproduction was 6.2 (SD=1.81).

Cps Bird & Crozier:
- 50% of every 1000 female chicks recruit by age 11
- Mean age at 1st reproduction was 6.8 (SD=1.95).

Summary:

Apparent survival varied by colony, reproductive status, age & year. While annual variation is high, the environmental covariates we investigated only explained a small amount of this variation. Survival rates were significantly lower for Cp Royds compared to Cps Bird & Crozier, as observed in previous analysis of breeding birds of unknown age. This decreased survival rate for Pre-Breeders in particular at Cp Royds, resulted in far fewer birds being recruited into the breeding population per 1000 female chicks produced at Cp Royds compared to the two larger colonies. This difference in survival rates across all reproductive states is likely one of the demographic mechanisms responsible for maintaining large colony size discrepancies on Ross Island.